JARQ 25, 133–140 (1991)

Nitrogen and Carbon Dynamics in Citrus Trees in Orchards

Nobuo TAKAGI and Satoshi AKAMATSU
Ehime Prefectural Fruit Tree Experiment Station (Matsuyama, Ehime, 791-01 Japan)

Abstract
Influences of flowering intensity and spring weeds on ^{15}N uptake by citrus trees were examined with Miyauchi-iyo (Citrus iyo hort, Tanaka) and Satsuma mandarin trees. In highly flowering Miyauchi-iyo trees, total nitrogen contained in fallen flowers accounted for more than 10% of the nitrogen in the fruits harvested in autumn. The fruit setting under leafy inflorescences was improved by nitrogen supply prior to anthesis. The ovary growth rate during the period of 4 to 5 days before the full-blooming stage was greater in leafy inflorescences than in leafless ones. The ^{15}N applied in soils in early September was absorbed and translocated into shoots, leaves and fibrous roots, and the contents remained almost constant during the winter season. However, in the period of March to May, the ^{15}N content in the old plant organs decreased concurrently with an increase in its content in new leaves and flowers. The ^{15}N applied in soils prior to anthesis (mid April) was absorbed and uniformly distributed to new shoots and flowers at anthesis. Abscised flowers contained a considerable amount of ^{15}N. This indicates that a great deal of nitrogen was lost through flower falls. On the other hand, the nitrogen applied in soils at the beginning of flowering (early May) had little effect on fruit setting, but it enhanced the development of new shoots after anthesis. A larger amount of ^{13}C-photosynthates were translocated into leafy inflorescences than into leafless ones. The ^{13}C contents in abscised flowers were rather low. Thus, it is presumed that nitrogen supply promotes translocation of photosynthates to flowers, resulting in an increase of fruit setting. Spring weeds weighed 32.3 t/ha. Total amount of nitrogen in the weeds was 105 kg/ha, which was equivalent to 38.6% of the ^{15}N applied in early spring. When the cut weeds were mulched, nearly 75% of the ^{15}N disappeared by September. This nitrogen was partly transferred to soils and partly reabsorbed by the citrus trees. As a consequence, in the weed plot, the ^{15}N contents in leaves and fruits of the trees increased in September and beyond, while in the open ground plot, the ^{15}N contents in flowers and leaves were higher in early summer.

Discipline: Soils, fertilizers and plant nutrition/Horticulture
Additional key words: ^{13}C-photosynthates, inflorescence, ^{15}N uptake, ovary, spring weed

Introduction

Miyauchi-iyo and Ohmishima navel orange trees, both of which flower in profusion, are generally not vigorous in plant growth and low in fruit yield in Japan. In producing high yields of these varieties, tree growth and fruit setting, rather than flower numbers, are vital factors[2,13]. Growth of spring flushes, fruit setting and fruit development are suppressed, when the nitrogen supply is limited[6–8]. The decreased supply of nitrogen to each organ is caused by not only the reduced amount of nitrogen applied as fertilizers but also by the competitions between vegetative and reproductive organs as well as between citrus trees and covering sod, or spring weeds[4,10–12].

Guardiola et al.[2] reported that in 16-year-old Washington navel orange trees, the nitrogen contained in abscised flowers amounted to 171 g per 1,000 flowers. Ichiki[4] also estimated the amount of nitrogen absorbed by covering sod was 380 kg per ha a year in citrus orchards in Japan. When the flower numbers are plenty and the orchard is covered densely with green sward, the supply of nitrogen to the persisting ovary and spring flushes is seriously hampered. It is therefore highly useful to know a nutritional demand in plant organs during the anthesis and a nutritional competition between citrus trees and covering green sward in rationalizing fertilization practices.

The recent development of techniques in the use of ^{15}N-labelled fertilizer and ^{13}C-labelled carbon dioxide has enabled researchers to undertake in-depth studies on absorption and translocation of plant nutrients. One of the examples of effective use of this technique is, among others, related to the studies on plant nutrition in satsuma mandarin trees. The results of those studies have greatly contributed to rationalizing fertilizer applications in Japan[5,8,9].

Loss of nitrogen through flower abscission

With an increase of flowers in number in citrus trees, the number of spring flushes decreased at a rate of one shoot to five flowers. When leafless inflorescences were large in number, fruit setting was below 10%[12]. It was however observed that flower organs were always rich in nitrogen contents regardless of flowering load and persistency. This implies that the flowers of citrus trees drop in company with a great loss of nutrient of nitrogen.

Fig. 1 and Table 1 show the loss of nitrogen caused by flower abscission, fruit thinning and harvesting in 8-year-old Miyauchi-iyo trees. The nitrogen contents in flowers were 3.59% and one flower contained 2.4 mg of nitrogen on an average. A total amount of nitrogen in the abscised flowers increased linearly with the increasing intensity of flowering. When

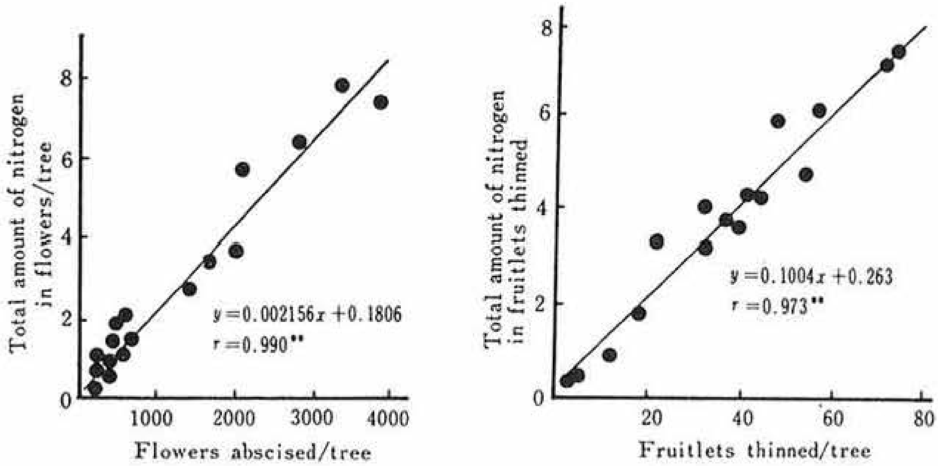

Fig. 1. Relationships between the number of flowers (left) or fruitlets thinned (right) and their total amount of nitrogen per tree
Data from 20 trees of 8-year-old Miyauchi-iyo trees.
Source: Takagi et al. (1987)[13].

Table 1. Loss of dry matter and nitrogen caused by flower abscission, fruit thinning and harvest[a)]

Organ	Dry matter (mg)		No. of organs /tree	No. of leaves /flower or fruit	No. of abscised organs /tree	Content of N (%)				N in abscised organs (mg)	N in abscised organs (g)	
	Ovary	Whole flower				Ovary	Petal	Calyx	Flower		/tree	/ha[b)]
Flower(s)		67.0	994	10.3	858				3.59	2.4	2.14	430
Leafy	7.16					3.31	3.83	3.07				
Leafless	6.87					3.62	3.80	3.30				
Fruit												
Thinned		7,000	136	39.0	67				1.63	113.9	7.60	1,520
Harvested		32,000	69	76.5	69				0.98	313.6	21.76	4,350

a): Data present averages of 20 trees of 8-year-old Miyauchi-iyo trees.
b): In the case of 2,000 trees/ha planted.
Source: Takagi et al. (1987)[13].

the number of flowers were 8,000 per an established tree, the loss of nitrogen amounted to 19.2 g per tree. This amount is converted to 38.4 kg of N per ha contained in 2,000 trees, which are the most popular planting density in Miyauchi-iyo orchards, and are equivalent to 76.8 kg of fertilizer nitrogen per ha on the assumption that 50% of the fertilizer nitrogen is absorbed by those trees.

^{15}N translocation of applied nitrogen to vegetative and reproductive organs

Fig. 2 shows seasonal changes in utilization of the ^{15}N applied in early September to 9-year-old Miyauchi-iyo trees. Most of the nitrogen applied was steadily absorbed until mid November. The ^{15}N contents in leaves and roots remained almost constant until February. As the trees grew up further, the ^{15}N contents of shoots, leaves and fibrous root decreased concurrently with its increase in new organs. In September, the new leaves contained ^{15}N at a level of 80% as much as those in May. This

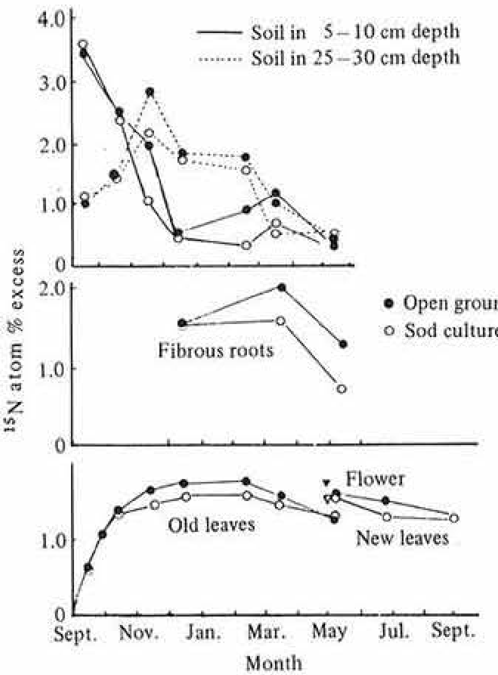

Fig. 2. Seasonal changes of ^{15}N content in soils, fibrous roots and leaves of Miyauchi-iyo trees
^{15}N was applied as $(^{15}NH_4)_2SO_4$ to soils on September 1, 1983.
Source: Takagi et al. (1987)[13].

Table 2. Distribution of ^{15}N applied before and at anthesis

Treatment[a)]	Flower organ: Ovary		Petal		Calyx		Spring flushes	Fruitlets		Spring flushes	Old leaves	Abscised flowers
	Leafy	Leafless	Leafy	Leafless	Leafy	Leafless		Leafy	Leafless			
Total N (%)	May 12							June 15				
^{15}N Urea folia spray I	2.81	2.50	3.30	3.19	2.61	2.05	3.08	2.69	2.96	2.74	2.18	3.39
II	2.58	2.55	3.15	3.20	2.41	2.28	—	—	—	—	—	—
$(^{15}NH_4)_2SO_4$ soil application												
April 20	2.41	2.66	3.18	3.15	2.51	1.95	3.07	3.41	3.18	3.13	2.62	3.00
May 8	2.78	2.52	2.59	2.72	2.07	2.11	2.57	3.68	3.10	3.33	2.97	2.60
Control	2.72	2.49	2.95	2.51	2.24	2.04	2.71	2.44	2.32	2.59	2.05	2.62
^{15}N Content (%)												
^{15}N Urea folia spray I	13.0	12.2	12.7	11.3	12.1	11.8	16.0	14.0	13.4	16.7	16.3	18.2
II	10.9	11.6	9.1	10.0	9.5	9.5	6.1	—	—	—	—	—
$(^{15}NH_4)_2SO_4$ soil application												
April 20	11.9	11.8	15.2	13.4	11.8	12.7	11.6	32.5	32.4	18.6	17.9	20.0
May 8	3.9	3.1	3.3	2.7	3.6	3.1	3.0	39.7	40.0	26.1	21.9	8.5

a): Spray I: ^{15}N was applied at anthesis (May 8), II: ^{15}N was applied before anthesis (April 20). Source: Takagi et al. (1987)[13].

indicates that the most part of nitrogen in inflorescences and spring flushes was composed of the nitrogen that was absorbed in autumn of the preceding year[1].

Patterns of the ^{15}N distribution in 4-year-old Miyauchi-iyo trees after its application before and at anthesis are shown in Table 2. The ^{15}N was applied in the soil 3 weeks before full bloom (April 20), or sprayed at the beginning of flowering (May 8). A great amount of ^{15}N was already translocated to spring flushes and flower organs before the stage of full blooming. A higher level of ^{15}N accumulation was observed in newly growing parts. However, no difference in ^{15}N was seen between persisting and abscising flowers, and between flowers and spring flushes. The level of ^{15}N in flowers at anthesis was lower when fertilizer N was applied on May 8 than that applied on April 20. However, in fruitlets and spring flushes, it was higher under the fertilization on May 8.

Effects of nitrogen supply on fruit setting, assimilation and translocation of ^{13}C

Table 3 shows effects of nitrogen application on fruit setting. There was a close relationship between the fruit setting and the ^{15}N content in spring flushes and flowers. The growth of flowers and ovaries during the period of 4 to 5 days before full blooming is shown in Fig. 3. At the pre-flowering stage, the ovaries were smaller than the petals and calyxes on a dry weight basis. No significant difference in the weight of flowers and ovaries was observed between the leafy and leafless inflorescences as well as among the trees with different flowering load. However, at the full blooming stage, the weight of ovaries was significantly greater in the leafy inflorescences than the leafless ones, especially in the trees with a low flowering intensity. It is presumed that the leaves of inflorescences give rise to a high level of fruit setting. These results indicate that there might be a high correlation between the growth rate of ovaries during the anthesis and the persistency of flowers.

Effects of nitrogen supply during the anthesis on assimilation and translocation of ^{13}C were examined[13]. The $^{13}CO_2$ (91 atom %) generated from 15 g of $Ba^{13}CO_3$ was applied to whole plants of 4-year-old Miyauchi-iyo at anthesis for 5 hr in an acryl chamber. Table 4 shows changes in the distribution pattern of ^{13}C after application. A great amount of ^{13}C was found in spring flushes and old leaves in 6 hr after application. However, the ^{13}C content declined later on: the decreasing rate during the 5-day period was greater in old leaves than in spring flushes. When comparisons were made on a basis of percentages of ^{13}C in the whole tree, it was found that the spring flushes showed a fairly consistent level of ^{13}C during the experimental period, whereas the old leaves declined concurrently with increasing concentrations in inflorescences.

Table 5 indicates ^{13}C contents in various flower organs in 5 days after application. Leafy flowers had a higher level of the contents than leafless flowers had. Persisting flower organs showed a greater content than abscised flowers. The ^{13}C content was highest in ovaries, followed by petals and calyxes in leafy inflorescences. This tendency however was not found in leafless inflorescences. These results suggest that the nitrogen supply during anthesis provide better translocation of photosynthates to flowers, especially to ovaries, resulting in improved fruit setting.

Nitrogen supply after anthesis also promotes vegetative growth in spring flushes and fibrous roots. It was observed that a foliar spray of ^{15}N urea in mid June increased ^{15}N content to the level of 3% of the total nitrogen in new leaves. In addition, it increased a chlorophyll content in the leaves.

From the above results, it may be concluded that nitrogen supply to flowers before anthesis is effective for improving fruit setting, because a large amount of nitrogen is taken away with flower abscission in case blooming is heavy, and that a nitrogen application may also be recommendable during or even after anthesis for the purpose of supplementing the nitrogen loss.

Effects of cover crops on ^{15}N uptake by citrus trees

An experiment was implemented to examine effects of the covering weeds on the uptake of fertilizer nitrogen applied to 8-year-old satsuma mandarin trees in spring[12]. The orchard was located on a gentle slope land with granite soils.

All weed plants were killed with herbicides (terbacil + diuron) prior to their germination in early spring.

Table 3. Effects of nitrogen application before and at anthesis on fruit setting in 5-year-old Miyauchi-iyo trees

Treatment	No. of leaves/tree	No. of flowers/tree	No. of fruit set/tree		Fruit setting (%)	Dry weight/fruitlet a month after anthesis (g)
			Leafy	Leafless		
^{15}N Urea foliar spray	400	189	22	21	22.8	0.41
$(^{15}NH_4)_2SO_4$ soil application						
April 20	341	147	15	21	24.5	0.59
May 8	329	163	9	7	9.8	0.38
Control	418	174	9	8	9.8	0.16

Source: Takagi et al. (1987)[13].

Table 4. Translocation of ^{13}C metabolites during anthesis in inflorescences and leaves of 4-year-old Miyauchi-iyo trees under orchard conditions[a)]

Organ		No. of organs /tree	Dry weight (mg)		C (%)	^{13}C content (%)		^{13}C/organ (μg)		^{13}C/tree (mg)	
			/organ	/tree		6 hr	24 hr	6 hr	24 hr	6 hr	24 hr
Flower buds											
Leafy	(large)	103	31.6	3,245	43.4	1.22	2.06	168	366	17.3	40.1
	(small)	317	11.7	3,717	41.1	1.19	1.95	57	94	18.1	29.6
Leafless	(large)	229	50.5	11,559	39.1	0.46	2.01	91	365	20.8	83.8
	(small)	190	6.5	1,241	39.1	0.45	0.72	29	19	2.2	3.4
New leaves				23,366	39.3	4.67	4.00			428.9	367.1
Old leaves				41,047	45.0	0.79	0.42			325.5	173.6

a): Samples were collected in 6 and 24 hr after $^{13}CO_2$ application.
Source: Takagi et al. (1987)[13].

Table 5. Translocation of ^{13}C metabolites in Miyauchi-iyo trees in 5 days after $^{13}CO_2$ application

Organ		No. of organs /tree	Dry weight (mg)		C (%)	^{13}C content (%)	^{13}C/organ (μg)	^{13}C/tree (mg)
			/organ	/tree				
Inflorescences								
Leafy	(ovary)	46	8.3	380	40.9	1.66	56	2.58
	(petal)	46	22.2	1,020	36.7	1.54	126	5.78
	(calyx)	46	27.3	1,255	40.9	1.44	161	7.39
Leafless	(ovary)	43	4.0	173	40.2	1.05	17	0.73
	(petal)	43	17.9	768	40.9	1.13	82	3.55
	(calyx)	43	21.9	941	40.9	0.85	76	3.28
Abscised	(ovary)	33	2.3	76	43.5	0.80	8	0.27
	(petal)	—	—	3,958	29.7	0.92		10.79
	(calyx)	—	—	879	40.9	0.61		2.18
Flower buds								
Leafy	(large)	147	38.1	5,606	43.4	1.54	255	37.42
	(small)	227	31.8	7,216	41.1	1.66	216	49.08
Leafless	(large)	119	49.2	5,852	39.1	1.15	220	26.21
	(small)	99	13.2	1,311	39.1	1.11	58	5.73
Abscised	(large)	34	35.8	1,273	36.3	0.38	49	1.68
	(small)	91	16.7	1,523	36.3	0.63	38	3.47
New leaves				23,366	39.3	2.61		239.40
Old leaves	(spring)			61,760	45.0	0.12		32.22
	(summer)			11,510	45.0	0.22		11.55

Source: Takagi et al. (1987)[13].

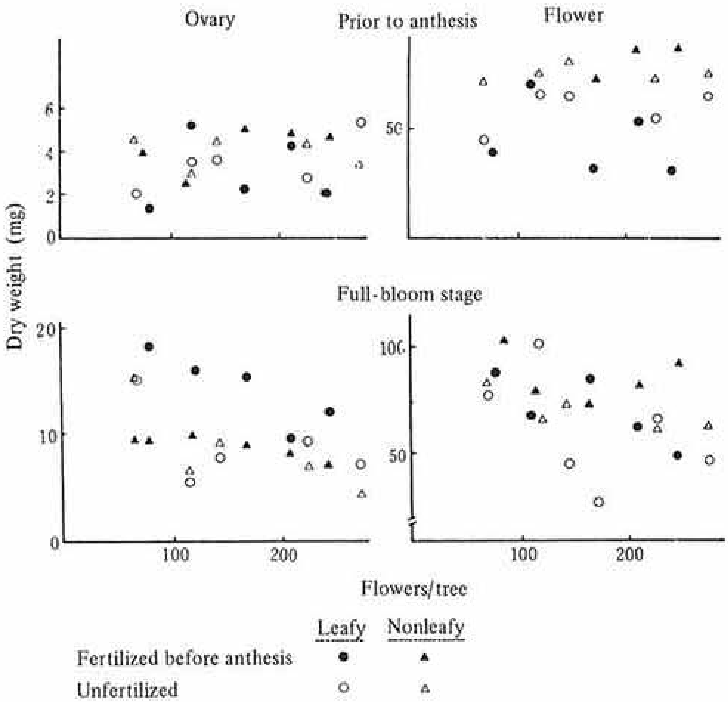

Fig. 3. Effects of nitrogen application on the weight of flowers and ovaries in connection with the number of flowers and the type of inflorescences
Source: Takagi et al. (1987)[13].

Table 6. Absorption of nitrogen applied in spring by weeds in the 8-year-old citrus orchard

Time of N appl.	Weight of weeds (kg) Fresh	Weight of weeds (kg) Dry matter	Content of N (%)	Amount of N in weeds (kg)	^{15}N atom % excess	Percentage of applied N (%)	Amount of applied N in weeds (kg)
Spring weeds (cut on May 12)							
Weeds	2,325	525	1.65	8.82	2.11	31.5	2.78
Roots	723	166	1.01	1.68	1.90	28.4	0.47
Total	3,048	691		10.50			3.25
Summer weeds (cut on July 21)							
Weeds	1,088	237	1.92	4.55	0.27	4.0	0.18
Roots	249	75	1.40	1.05	0.38	5.7	0.06
Total	1,337	312		5.60			0.24

Source: Takagi et al. (1985)[12].

In the weed plot, most weed roots were found in the surface soil, 0 to 5 cm deep, whereas most roots of the citrus trees extended in deeper soils below 5 cm. Soil temperature was consistently higher in the open ground plots than in the weed plots. At a depth of 10 cm, the soil temperature reached 12°C in the period of mid March to early April. It was very likely that nutrient uptake by trifoliate roots was greatly promoted when the soil temperature was above 12°C. This temperature was attained 20 days earlier in the open plots than in the weed plots.

The spring weeds weighed 32.3 t/ha (Table 6). Total nitrogen content contained by the weeds was 105 kg/ha, and 38.6% of the ^{15}N applied was

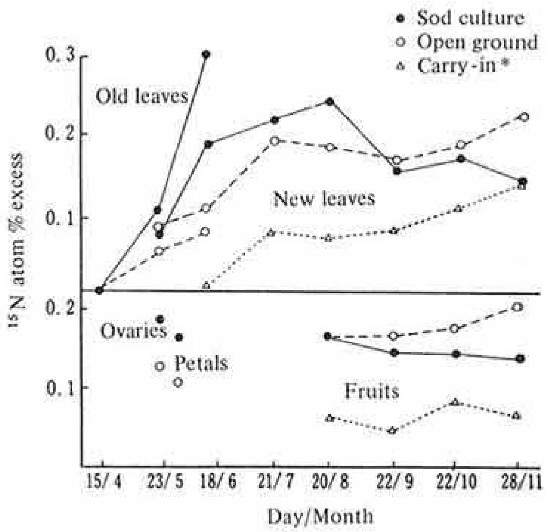

Fig. 4. Seasonal changes of ^{15}N contents in leaves and fruits of satsuma mandarin trees under different weed conditions
^{15}N was applied on May 8 in the form of $(^{15}NH_4)_2SO_4$.
* ^{15}N-applied sod harvest was supplied to the non-N fertilizer plot.
Source: Takagi et al. (1985)[12].

absorbed by those spring weeds. When the cut weeds were mulched, nearly 75% of the ^{15}N disappeared by September; some part of which was transferred to soils and absorbed by the citrus trees.

Fig. 4 shows seasonal changes of ^{15}N in leaves and fruits. In the open plots, the ^{15}N content in flowers and leaves was high in early summer. However, in the weed-mulching plots, the content in leaves and fruits gradually increased in September and beyond. This may probably suggest reabsorption of the ^{15}N released from the mulched weeds.

Total carbon and nitrogen contents in the soil were lower in the open plots in mid May. However, the ^{15}N content in the soil at a depth of 20 cm was higher in the open plots than in the weed plots. However, the contents declined considerably by late July in the open plots, whereas a large part of the ^{15}N was retained in the weed plots.

Total amount of the ^{15}N absorbed by the trees over 13 months was smaller than that remaining in the soil. The percentages of ^{15}N remaining in the soil were 29.7 and 63.6% in the open and weed plots, respectively. However, nearly 90% of the ^{15}N in the soil was found in the surface soil in those two plots.

The above results show that the presence and the absence of spring weeds in citrus orchards gives a great effect on the uptake pattern of nitrogen applied in early spring.

References

1) Akao, S., Kubota, S. & Hayashida, M. (1978): Utilization of reserve nitrogen, especially, autumn nitrogen, by satsuma mandarin trees during the development of spring shoots (I). *J. Jpn. Soc. Hort. Sci.*, **47**, 31–38 [In Japanese with English summary].

2) Guardiola, J. L., Garcia-Mari, F. & Agusti, M. (1984): Competition and fruit set in the Washington navel orange. *Physiol. Plant.*, **62**, 297–302.

3) Hirobe, M. & Ogaki, C. (1969): Studies on the absorption of nutrients elements by Unshiu orange trees. 1. On the seasonal absorption of nutrient elements by adult trees. *Bull. Kanagawa Hort. Exp. Sta.*, **17**, 18–26 [In Japanese with English summary].

4) Ichiki, S. et al. (1976): Nitrogen dynamics in the sod citrus orchards. 2. Absorbance in weeds and decomposition. *Abst. Annual Meet. Jpn. Sci. Soil Manure*, **22**, 89 [In Japanese with English summary].

5) Kato, T. (1986): Nitrogen metabolism and utilization in citrus. *Hort. Rev.*, **8**, 181–216.

6) Kubota, S., Fukui, H. & Motoyama, E. (1974): Effects of the period of intensive application of nitrogen on growth and chemical composition of unfructified satsuma mandarin trees. (1). On growth, absorption of nitrogen and composition of carbohydrates. *Bull. Shikoku Agr. Exp. Sta.*, **28**, 105–131 [In Japanese with English summary].

7) Kubota, S. et al. (1976): ^{15}N absorption and translocation by satsuma mandarin trees. 3. Behaviour of nitrogen supplied in early spring. *Bull. Shikoku Agr. Exp. Sta.*, **29**, 49–53 [In Japanese with English summary].

8) Legaz, F. & Millo, E. P. (1981): Dynamics of ^{15}N-labelled nitrogen nutrients in Valencia orange trees. *In* Proc. int. sci. citriculture, 575–582.

9) Nakahara, M. et al. (1985): Studies on nitrogen absorption and translocation using ^{15}N-tracer in adult trees of satsuma mandarins, with special reference to the improvement of fertilizer application. *Bull. Saga Fruit Tree Exp. Sta.*, **3**, 62–87 [In Japanese with English summary].

10) Sato, Y. et al. (1978): Studies on the application of nitrogen fertilizer in the apple orchard. *Bull. Fukushima Hort. Exp. Sta.*, **8**, 1–16 [In Japanese with English summary].

11) Suzuki, K. (1981): Weeds in citrus orchards and their control in Japan. *In* Proc. int. soc. citriculture, 489–492.

12) Takagi, N., Akamatsu, S. & Shimizu, M. (1985): Effect of spring cover crops on the ^{15}N uptake by citrus trees under orchard conditions. *J. Jpn. Soc. Hort.*

Sci., **54**, 307–314 [In Japanese with English summary].
13) Takagi, N. et al. (1987): Influence of flowering intensity on the vegetative growth and translocation of ^{15}N and ^{13}C-photosynthates during anthesis in Miyauchi-iyo. *J. Jpn. Soc. Hort. Sci.*, **55**, 434–444 [In Japanese with English summary].
14) Wallace, A. et al. (1954): Translocation of nitrogen in citrus trees. *Proc. Amer. Soc. Hort. Sci.*, **64**, 87–104.

(Received for publication, May 13, 1991)